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OIPE JUL 0 6 2005 PATENT & TRADEMARK OFFICE

Attorney Docket No. 14XZ130599/GEM-0105

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Application of DA SILVA ET AL.	: METHOD AND ASSEMBLY FOR PROCESSING , VIEWING AND INSTALLING COMMAND INFORMATION TRANSMITTED BY A DEVICE FOR MANIPULATING IMAGES
Application No. 10/722,844	: Art Unit: 2122
Filed 11/26/2003	: Examiner:
	: Confirmation No. 6558
	: Date: July 6, 2005

INFORMATION DISCLOSURE STATEMENT

[x] 1. Pursuant to 37 CFR 1.97(b)
[within three months of national, non-CPA filing or prior to first Office action on the merits, or prior to first Office action after filing an RCE] *(no charge)*

[ ] 2. Certification Pursuant to 37 CFR 1.97(c)
[before Final Office Action or Allowance] *(no charge)*

[ ] 3. Fee Payment Pursuant to 37 CFR 1.97(c)
[before Final Office Action or Allowance or other action closing the prosecution] *(charge: $180.00)*

[ ] 4. Certification & Fee Payment Pursuant to 37 CFR 1.97(d)
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The following are submitted in the above application in compliance with 37 CFR 1.97 and 37 CFR 1.98.

[x] 5. A list of documents on Form PTO-1449 or Substitute together with copies of each identified document and a translation thereof or a concise explanation of each non-English language document or a Search Report or communication from a non-US patent office or an International Search Report from an International Searching Authority for a patent application filed via the Patent Cooperation Treaty or document (s) cited in the application or the priority application.

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Jay L. Chaskin

Date: July 6 2005

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☐ Enclosed is a check in the amount of $__________in payment of all applicable fees associated with the submittal of this Information Disclosure Statement.

An original and two (2) copies of this document is enclosed.

Respectfully submitted,

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Substitute for form 1449/PTO

INFORMATION DISCLOSURE STATEMENT BY APPLICANT

(Use as many sheets as necessary)

Sheet 1 of

Complete if Known	
Application Number	10/722,844
Filing Date	11/26/2003
First Named Inventor	Da Silva, Sonia
Art Unit	2122
Examiner Name	
Attorney Docket Number	14XZ130599(GEM0105)

U. S. PATENT DOCUMENTS

Examiner Initials*	Cite No.[1]	Document Number Number-Kind Code[2] *(if known)*	Publication Date MM-DD-YYYY	Name of Patentee or Applicant of Cited Document	Pages, Columns, Lines, Where Relevant Passages or Relevant Figures Appear
		US- 4 875 180	11-15-1988	Dietrich et al.	
		US- 6 191 784 B1	02-20-2001	Buxton et al.	
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FOREIGN PATENT DOCUMENTS

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PTO/SB/08B (08-03)
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Examiner Name	
Attorney Docket Number	14XZ130599 (GEM0105)

Sheet 2 of

NON PATENT LITERATURE DOCUMENTS

Examiner Initials*	Cite No.[1]	Include name of the author (in CAPITAL LETTERS), title of the article (when appropriate), title of the item (book, magazine, journal, serial, symposium, catalog, etc.), date, page(s), volume-issue number(s), publisher, city and/or country where published.	T[2]
		STORK ET AL., "Efficient and Precise Solid Modelling Using a 3D Input Device", Proc. of the Fourth Symp. on Solid Modelling and Applications,	
		vol. Symp. 4, pages 181-194, May 14-16, 1997	
		"3D Motion Controller User's Manual", March 2002, 3DCONNEXION, INC., 6505 Kaiser Drive, Fremont, CA 94555, 25 pp.	
		STORK, A., "Effiziente 3D-Interaktions-unde Visualisierungstechniken fur benutzerzentrierte Modellierungssystems", Aug. 18, 2000, Technishen	
		Universitat, Darmstadt, Germany, 186 pp.	

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INFORMATION DISCLOSURE STATEMENT – CONCISE EXPLANATION OF EACH NON-ENGLISH DOCUMENT

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Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

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Document	Concise Explanation
Stork, A. "Effziente 3D-Interaktions- Unde Visualisierungstechniken fur benutzertriete Modelierungssystems", 18 August 2000], Technishen Universitat, Darmstadt, Germany 186 pp., page 7, line 1 to page 13, line 17; page 80, lines 1 to page 89, line 3;	[Translation from German] [Excerpt from dissertation submitted by André Stork on Aug.18, 2000, Pages 7 - 13] **2. Prior Art** In view of the stated theme of the present work, various are of significance. Here, 3D interaction techniques play the principal role. Visualization techniques should make use of the known psychology of perception by the human perceptive apparatus. Therefore, basics of shape and depth perception will be presented in this chapter. Besides, system architectures of CAD and VR systems are important for the conception of a user-centered modeling system. This chapter gives a survey of the present state of the art in these fields and on the input and output device technology and evaluates them in view of the modeling requirements.

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Jay L. Chaskin

Date: July 6, 2005

2.1 3D Input Devices

3D input devices were developed to make as natural and intuitive an interaction possible for the user in 3-dimensional, computer-generated scenes. 3D input devices make it possible to carry out true 3D interactions, and thus offer disadvantages in principle over 2D input devices, with which 3D interactions must be re-perceived as sequences of 2D interactions. 3D input devices as a rule put six degrees of freedom at the user's disposal, namely three for the positioning and three for the orientation in space. 3D input devices may be divided into these three categories:

- 'Flying' Devices
- Gesture-Controlled Devices
- 'Tabletop' Devices [74].

These three categories are briefly illustrated below, a relevant representative of each being presented and evaluated from the aspect of suitability for modeling assignments. Next, the requirements imposed by CAD on these devices will be discussed.

2.1.1 Requirements for 3D Input Devices, in the View of CAD

Within this section, the requirements that 3D-CAD imposes on 3D input devices will be formulated. In the analysis of requirements and evaluation, statements in [174], [144], [94] and [57] will be recalled and supplemented with aspects of 3D modeling [149].
The development of 3D input devices was advanced primarily in the field of "virtual reality." The aim of VR systems consists primarily in allowing the user to dive into an artificial, computer-generated world. The user (otherwise known in VR as a cybernaut) can manipulate his way through the virtual environment and manipulate objects by means of multidimensional interaction techniques. He can integrate with these objects in an "accustomed" manner, i.e. grasp them, move them and release them again. Upon entering the virtual world, as a rule the objects are already present (among the applications in VR, the modeling of objects represents an exception). A compact introduction to methods, techniques and fields of application of virtual reality is offered in [10] and [11].

Modeling functionality, such as the generation and modification of objects, is supported by VR systems in exceptional cases only. In contradistinction to VR systems, these are core functionalities of a modeling system. With a modeling system, it must be possible to generate and modify objects exactly, i.e. objects must be accurately dimensionable. Designers often work with their CAD system for several hours daily; therefore, different requirements are imposed on the fitness of the input devices for use than in VR. 3D input devices for modeling assignments should satisfy the following requirements:

- They should be precise, i.e. points in space must be exactly determinable.
- Their radius of action must not be limited, since in principle, the construction space is unbounded.
- Rotation through angles of rotation of any size must be simple to execute.
- They must be ergonomic, to facilitate use over a fairly long period of time.
- They must not limit the user, so that he can continue to execute 2D interactions and/or keyboard inputs.
- They should give the user suitable "feedback" when force is applied, to facilitate operation.
- They should be economical compared to the costs of a CAD work station.

2.1.2.1 The SpaceMouse - A Tabletop Input Device

The SpaceMouse [98] is a tabletop 3D input device, making available six degrees of freedom (see Fig. 1). The SpaceMouse offers nine freely-programmable keys and a movable cap, realizing the six degrees of freedom. To deflect the cap, some force must be exerted. The cap of the SpaceMouse responds with a motion within narrow limits (±1.5 mm in translation, and ±4 degrees in rotation). This form of feedback gives the user a feeling for how far he has deflected the cap.

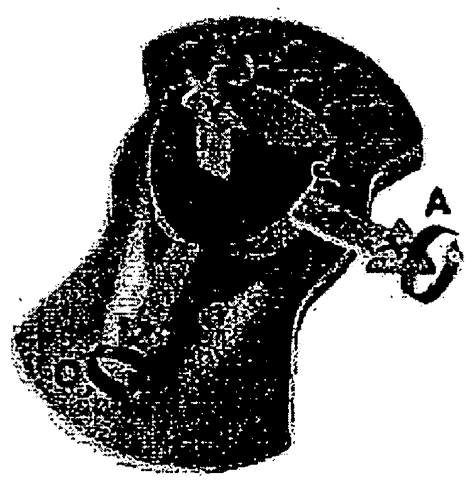


Fig. 1. The SpaceMouse [98]

The quantities delivered by the SpaceMouse are relative position and rotation data. In other words, they indicate the translatory and/or rotational changes in the latest time interval. If the cap of the SpaceMouse is pressed uniformly in one direction, the corresponding graphic object will move accordingly. The greater the deflection of the cap of the SpaceMouse, the greater the resulting translation/rotation quantity, i.e. the faster the corresponding object will move.

2.1.3 The Polhemus Sensor - A Flying 3D Input Device

"Flying" 3D input devices are devices attached to the user's hand or held in the hand and moved in space. The position and orientation of the input device and/or the hand in space is determined e.g. by means of an electromagnetic field. In the following, the Polhemus sensor [1] is described, representing one of the most-used flying systems.

The Polhemus sensor, hereafter also called briefly Polhemus, is a 3D position and orientation sensor, used independently or in combination with other input devices, e.g. the data glove (see section 2.1.4). To determine 3D position and orientation, the Polhemus uses an electromagnetic coupling between a transmitter and a receiver. The transmitter is placed in a fixed position in space, while the Polhemus sensor, which represents the actual 'receiver,' can be moved in space freely. The absolute position and orientation of the sensor in the electromagnetic field emitted by the transmitter, is determined cyclically. For evaluation of the position and orientation, the sensor is connected by a cable to the computer, or an interface station, which performs the determination of position.

2.1.4 The Data Glove - A Gesture-Based Input Device

The Data Glove [10] in combination with flying 3D input devices, forms the classical input technology for VR systems. The Data Glove picks up the hand and finger movements of its user. From the placement of the fingers, manual gestures can be interpreted, which then trigger corresponding interactions. Typically, the Data Glove is used in combination with a position and orientation sensor (e.g. the Polhemus), which determines the absolute position and orientation of the hand in space.

The recognition of the finger position by the Glove generally takes place by way of an optical measuring system. The Glove is provided on the upper side of the hand with thin glass fiber cables which span the fingers. One end of each glass fiber cable is provided with a luminescent diode and the other end with a phototransistor, which measures the arriving light of the diode. The curvature of a finger joint reduces the incoming light energy, which conveys information about the position of the finger. Conventional Data Gloves register up to 16 different finger positions.

In VR systems, motions of the user's hand are often transmitted to a graphic echo in the form of a virtual hand. The virtual hand corresponds to the real motions, making possible a natural and intuitive navigation and manipulation. Within the 3D system, the gestures and motions of the user are followed by the virtual hand.

Through the accustomed course of movement, the user can grasp objects, move them and release them again, so the interaction is highly intuitive. The Data Glove is usually employed in immersive applications, that is, applications in which the user is fully involved in the representation of the computer-generated scene. Complete immersion is achieved by head mounted displays [42].

2.1.5 Other 3D Input Devices

Besides the input devices here described in more detail, the market offers a steadily increasing number of other 3D input devices. Besides the SpaceMouse and the SpaceBall, and the various Data Gloves, 3D input devices with tactile feedback and devices with force feedback (Phantom [181]) or else wireless 3D input devices [112] are beginning to establish themselves. Beyond this, input devices are being developed for special applications, such as deformation of objects [103]. Other scientists are trying to improve possibilities of input without an explicit input device; mention may be made here primarily of video-based systems that pick up special markings and determine the position of these points in space [137] with the aid of image recognition methods. A survey of input device technology will be found under [32].

2.1.6 Evaluation and Selection of 3D Input Devices

In the following, the input devices presented will be evaluated as to their suitability for the modeling process at the traditional workstation. It should be noted that the environment in which a 3D input device is to be employed affects the priorities of the above-mentioned requirements decisively and thus co-determines the nature of the preferred input devices. Thus, tabletop devices seem better suited to the conventional workstation. The Virtual Desk (cf. chapter 2.3.3), on the other hand, suggests the use of flying devices. Also, the Virtual Desk makes access to a normal keyboard more difficult, and other input modes (e.g. spoken commands) gain importance.

The SpaceMouse exhibits very good ergonomics. Its cap is comparatively flat and can be conveniently grasped by the hand, so that hardly any manifestations of fatigue occur. The measuring mechanism of the SpaceMouse is simple, insensitive to manifestations of wear, and highly precise. Furthermore, the SpaceMouse is relatively economical compared to magnetic trackers. Thus, it fulfills the said requirements for a 3D input device for a conventional CAD work station in exemplary manner. A disadvantage of tabletop devices is that they will only indirectly allow 3D interactions (cf. section 2.2).

The advantage of flying input devices, namely the possibility of direct 3D interaction (cf. section 2.2) is at the same time its greatest disadvantage: The fact that they must be guided by the hand and arm in front of the body soon leads to fatigue. Another disadvantage is the usually necessary cabling of the user. The devices are not suitable for operation over a prolonged period. Besides, flying devices generally yield absolute space positions, i.e. the interaction space is predetermined. A 'freezing mechanism' must be realized if the hand is to be movable without influencing the graphic echo, so that the graphic echo can be displaced out beyond the physical tracking region.

Electromagnetic tracking systems exhibit the following disadvantages in view of the requirements of 3D modeling:

- The sensor is trouble-prone with respect to the influence of an outside field, so that even nearby metallic objects may interfere.
- The spatial resolution is limited, so that positions cannot be detected or computed with arbitrary precision.
- The reaction of the graphic feedback is in part delayed in time (owing to determination of position and noise suppression).

The Data Glove does not permit changing the input device or even merely 'releasing' the input device in a simple manner, e.g. to write a brief note of something. In other words, it resists being imbedded in the typical course of a designer's work. Use of a Data Glove over a period of any length is therefore unreasonable for modeling assignments. In the following, other reasons are given that militate against the use of a Data Glove within a 3D CAD system:

- Typical CAD interactions, such as, for example, rotation through a large angle, are troublesome to execute with the Data Glove, since the hand is subject to natural limitations of movement; in the case of large angles, an embracing becomes necessary.
- The Data Glove must be individually calibrated to the user's hand in order to get satisfactory results.
- The Glove is fits very snugly, and this becomes unpleasant during prolonged wear.
- The lack of force feedback is found troublesome; as a rule, the user gets no tactile feedback in grasping.
- Different devices are required for right-handed and left-handed people.

Some of the problems listed are solved or mitigated by new developments, e.g. the use of neuronal networks for gesture recognition [23] or by Gloves with tactile feedback (CyberTouch [182]) and force feedback (CyberGrasp [182]). However, experience with designers in the scope of user tests within the framework of this work allow the conclusion that the use of a Data Glove is not acceptable in daily work. In conclusion, here is a tabular comparison of the 3D input devices presented with respect to the formulated requirements.

Table 1: Comparison of Various 3D Input Devices as to Their Suitability for Use in Modeling Applications at the Conventional Work Station [99].

	Polhemus w/wo Mouse "Bat"	Data Glove	SpaceMouse
Precision	-	-	++
Unlimited action space	--	--	++
Unlimited angle of rotation	-	--	++
Ergonomy	--	--	++
2D input still possible	-	--	++
Feedback on application of force	-	-	+
Intuitive interaction	++	++	+
Price	-	--	++

Legend: ++ very good, + good, - poor, / high, -- very poor, / very high

2.2 3D Interaction

By 3D interaction is meant action of the user in computer-generated scenes. Here, a number of base (inter)actions may be distinguished:

- **Navigation**, i.e. targeted motion in the space, realized by changes of camera position and orientation.
- **Positioning**, i.e. placement of an object in a particular space position.
- **Orientation**, i.e. rotation of an object in space.
- **Selection**, and/or **de-selection**, i.e. choosing a point or object in space.

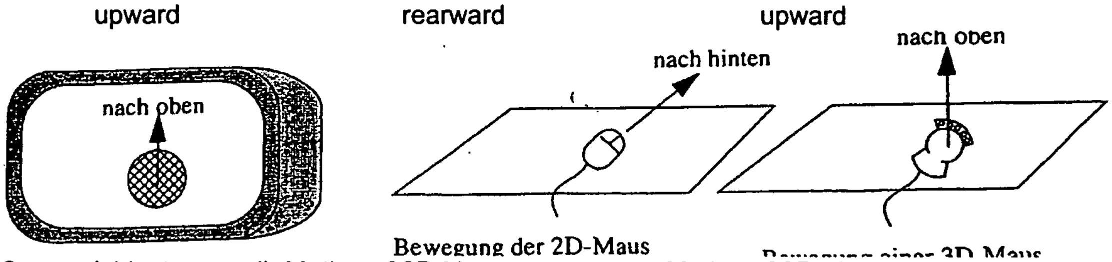
Positioning and orientation are often taken together, since the two are assignments that can be performed simultaneously with a 3D input device having six degrees of freedom.

From these base interactions, higher-grade interactions, such as moving of objects to a place, may be derived. For that purpose, first the graphic echo that represents the user in the scene (cursor or virtual hand) is taken to the object that is to be moved, and the object is selected. The object follows the ensuing hand or cursor movement, and is finally de-selected, or released.

Within the course of interaction, direct manipulation [141] is an important concept and one of the basic requirements imposed on graphic interaction systems. Direct manipulation is when actions lead immediately to a visible effect. In the ideal case, the time interval between action and visual feedback is no longer than 1/20 second. This corresponds to the rate of image repetition that is just sufficient to give the user the impression of a smooth motion. This ideal state is often not realizable, and investigations have shown that a time delay of up to one second is tolerated by users in certain applications. A delay of not more than one-tenth of a second should be a goal.

Another important concept is the so-called stimulus-response correspondence (or stimulus-response compatibility) [115], [59]. Stimulus-response correspondence is one of the fundamental requirements for intuitive man-machine intersection.

upward rearward upward



Screen (object upward) Motion of 2D Mouse No Stimulus-Response Correspondence Motion of 3D Mouse Stimulus-Response Correspondence

Fig. 2. Principle of stimulus-response correspondence.

A correspondence of stimulus and response is present when in response to a stimulus, e.g. a motion of the hand to the left, an object motion takes place in the same direction. In all interactions with real objects in the real world, stimulus and response correspond. In work with 2D use surfaces and the 2D mouse, on the other hand, there is no stimulus-response correspondence, since the mouse pointer moves upward on the screen, when the mouse is moved away from the user, 'rearward' (see Fig. 2). If there is no stimulus-response correspondence, then a mental mapping is required on the part of the user in order to execute the motion corresponding to the desired action.

Stimulus-response correspondence for 3-dimensional assignments, such as volume modeling, can be achieved only with 3D input devices, and minimized outlay and scope of mental mapping operations.

The concept of **direct** and/or **indirect 3D interaction** also becomes important in the course of the work, and will therefore be defined here. Direct interaction is present when the position of the user's hand coincides with the position of the graphic echo of the input device. Indirect interaction is present when the user's hand is not in the position of the echo of the input device. The conventional mode of operation with the 2D mouse is a form of indirect interaction, since the hand is not at the location of the mouse pointer. Operation with a Data Glove in an immersive environment, on the other hand, is for the most part in the nature of direct interaction.

[Translation from German]
Excerpt from dissertation submitted by André Stork on 18 August 2000, Pages 80 - 89]

4.2.6 Topology-Based Limited Modification Technique

So far, interaction techniques have been presented to produce primitives, and/or modify objects by the production of primitives, as in the case of the implicit Boolean operations. At this point, the topology-based limited modification technique ("topological-context based modification," or TCBM, for short) is to be introduced, as a new interaction paradigm, to manipulate primitives and their parameters in graphic-interactive manner. This novel formulation makes use of the advantages of the 3-dimensional input with its six degrees of freedom for object modifications with reduced number of degrees of freedom, such as are typical in the CAD. These include:

- Modification of one or more object parameters
- Rotation of an object about an edge
- Translation of an object in a plane

Liang and Green [94] developed the *region based reshaping* formulation, in which, as a function of the position of the 3D cursor, different object parameters could be modified. *Region based reshaping* has two serious disadvantages:

- In the case of complex objects, ambiguities result from overlap of regions with different significance for the manipulation.
- Interaction is not directly with the object, but with its periphery.

The topology-based limited modification technique solves these problems. The fundamental idea is to modify objects as a function of the selected topological elements, the geometrical context, and the motion then executed with the 3D input device (gesture). The modification initiated by the gesture depends both on the object type selected and on the geometrical givens at the position selected. The possible modifications are limited on this basis, so that with adjoining cursor movements, only manipulations having a small(er) number of degrees of freedom are possible. The cursor movement is limited accordingly. It is to be noted that although in the further course of interaction, only modifications having few degrees of freedom will run, this new interaction technique necessarily presupposes the six degrees of freedom of 3D input devices and makes use of them in advantageous manner for object manipulations by means of natural, intuitive gesture; there is no switching between different modes of modification, e.g. between translation and rotation. Gesture recognition passes over seamlessly into direct manipulation (see section 4.2.6.1). The principle of passing directly from a gesture into direct manipulation was presented by Rubine (125) for 2D gestures, and is here extended to 3D.

The term "gesture" is here understood as a translatory and/or rotational motion executed over a certain period of time by the user of a 3D input device. In the case of a tabletop input device, the gesture turns out to be the sum of the relative motions. This does not correspond to the meaning of the term gesture as used in VR systems, where as a rule, the term gesture is understood as a static attitude of the hand (in English, the term *posture*, which may be translated as *Pose*, best describes this situation). For gesture-based interaction, often elaborate operations, such as Neuronal Networks [24] or "Fuzzy Logic," are employed to compensate for the peculiarities of different users.

Survey of topology-based limited modification procedure:

1. Select a topological element
2. Execute a 3D gesture (rotation and/or translation of 3D input device)
3. Recognize the gesture, in light of the relevant context
4. If desired, represent a visual echo ("Center Shapes") to indicate the recognized gesture to the user
5. Limit the cursor movement, if necessary
6. Perform the direct manipulation
7. End the modification
8. Propagate the change through the system to the modeler

The first three steps may be accounted to gesture recognition, or classification, which will be described in the following.

4.2.6.1 Gesture Classification Phase

A direct manipulative system requires answering times in the range from one-tenth up to at most one second, i.e. there cannot be a wait of arbitrary length until the motion executed by the user with the 3D input device is recognized as gesture. Also, gesture recognition should function as robustly and stably as possible, and coincide with the intention of the user. So the aim must be the development of a rapid, simple and robust gesture recognition and classification, functioning user-independently to a large extent.

A gesture is classified, or recognized, with regard to the picked topological element and the local geometric features at the selected point. Local geometric features are considered to be normals, tangents and principal axes. In combination with tolerance thresholds, these features divide the design space into various parts, in terms of which the classification of the gesture executed is done. For this purpose, the results yielded by the 3D input device after the selection of a topological element are collected over a certain period of time and the resulting information is evaluated in terms of the classification spaces. Besides the spaces given by an

angle of tolerance, there is a threshold of rotation, transgression of which leads through the collected events to a rotation of the object. What interaction is met with after completion of gesture recognition depends on the picked object type (see chapter 4.2.6.2).

The procedure of gesture recognition, simplified, may be described as follows:
1. The user picks a topological element
2. The user executes a gesture
3. Over a certain period of time, the translatory and rotational results triggered by the gesture are collected
4. Now, a comparison is made to determine whether the rotational results have passed the rotational threshold, and if so, a rotation is initiated; otherwise, go on to 5
5. With the aid of the translatory results, a new (virtual) cursor position is computed.

This new cursor position is not visualized. With it, it is ascertained only in which partial space the cursor is located, and a corresponding translatory modification is initiated.

<u>Selection of a Topological Element</u>
Selection may concern a surface, edge or vertex. Fig. 43 shows the topological elements and their geometrical context, in terms of which the gesture recognition is carried out. Specifically, at the particular position picked, these are:
- For a surface *f*, the normal *n* and the principal directions *u* and *v*
- For an edge *e*, the tangent in the case of a curve, or the edge itself
- For a vertex *v*, its position

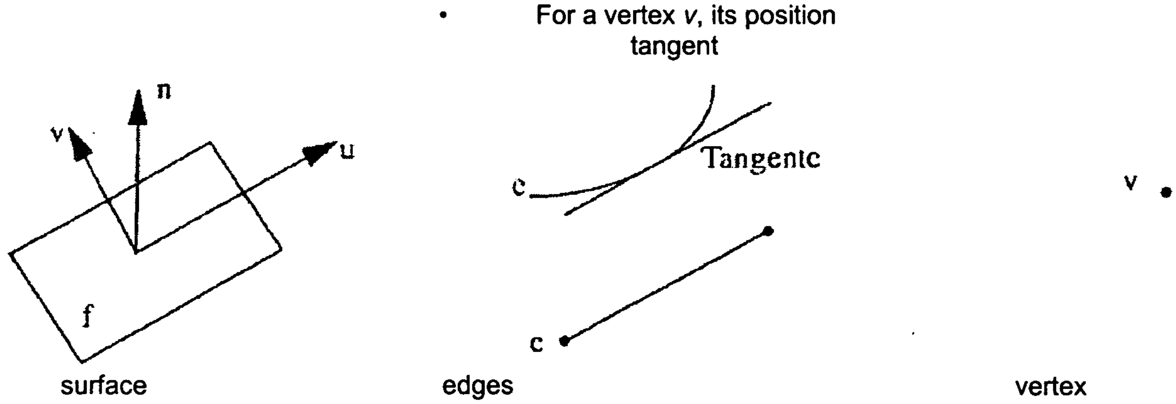
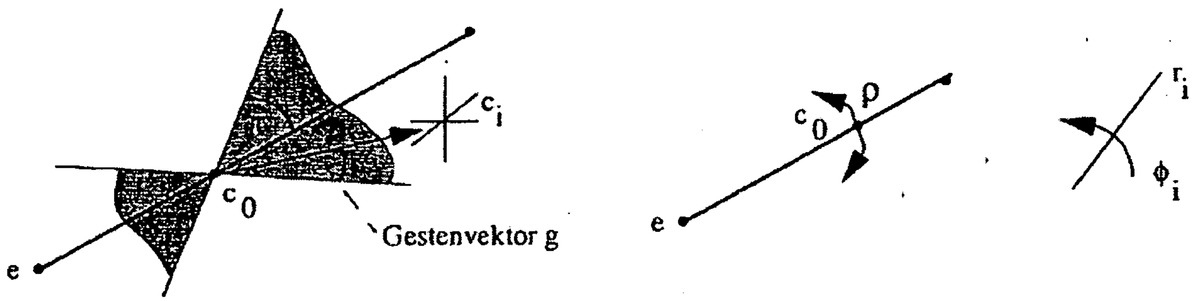


Fig. 43: Topological elements and their geometrical context

In terms of two thresholds, which may be adapted by the user, we now check whether a rotary motion or a translatory motion is present (see Fig. 44); this is most clearly illustrated by the example of an edge.

Definitions (cf. Fig. 44):
Let *e* be an edge (*e* will be understood in the following as a vector)
c_0 is the cursor position on the picked edge at gesture recognition time 0
c_i is the cursor position at a point in time $_i$
τ is the translation threshold angle
g is the gesture vector; equivalent to the 'rubber band' vector during object production
ρ is the rotation threshold angle
φ_i is the angle of rotation on the 3D input device at a point in time *i*
r_i is the corresponding angle of rotation



gesture vector g
Fig. 44: Threshold angle for classification of modification gesture

In combination with *e*, τ forms a partial space. If the cursor, after the gesture recognition period, lies in this space, all further cursor movements lead to translation of the object belonging to *e* in or against the edge direction. Another partial space is defined by τ and the plane for which *e* represents the normal to the surface. This partial space, for the sake of clarity, is not shown in Fig. 44. The interpretation of the partial space is object-type dependent (see chapter 4.2.6.2).

<u>Time Interval for Recognition of Gesture</u>
To ensure a system response after at most one second, this time interval is defined as an upper limit, within which a gesture must be recognized. Events for gesture recognition are collected until a certain number of events are present or the time barrier is past (in which case only the events collected so far are taken into account, which may adversely affect the recognition rate). In user tests, 12 events has crystallized out as the minimum for an input device operating at 50 Hz, such as e.g. the SpaceMouse. Then 12 events corresponds more or less to one-quarter second. Users not practiced in handling the SpaceMouse will, at the beginning of the interaction – while moving the cap in the desired direction – produce events that do not clearly go towards the intended gesture. For this reason, all events arriving within the first 0.2 second after the start of time measurement are ignored by gesture recognition. Thus, as a rule, a system response is assured after about half

a second (see Fig. 45). In the course of this interval z both the translatory and the rotational events of the 3D input device are picked up and processed as described below.

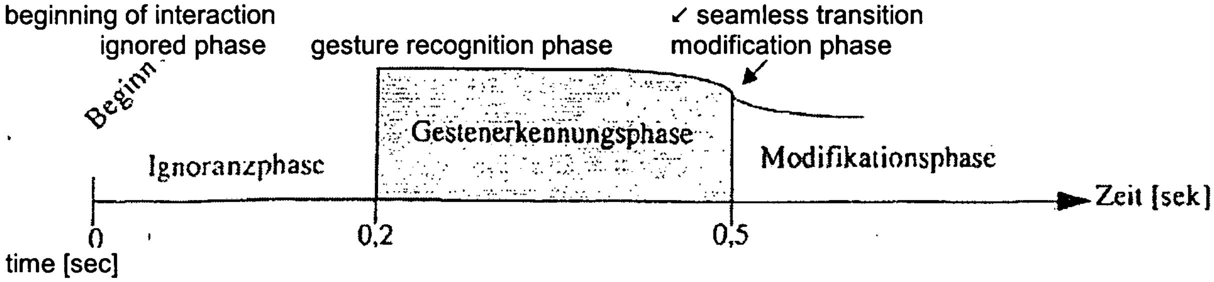


Fig. 45: Seamless transition of gesture recognition after modification

Calculation of Rotation and Translation

The rotation delivered by the 3D input device at any time *i* may be taken as axis and angle of rotation. For gesture recognition, in particular rotations about the axis or axes defined by the picked point, such as e.g. edge, normals to surface/principal directions, are relevant. Rotations whose axis is orthogonal thereto are not to play any part, and here again the stimulus-response correspondence is taken into account.

This means that the rotations over the gesture recognition period *z* for each event, i.e. at each time *i*, are imaged on the reference axis, and the angle of rotation about this axis must be determined. To obtain the angle with respect to this axis, the axis obtained from the gesture (understood as a standardized directional vector) is imaged on the reference axis about which rotation is to occur. The angle of rotation is multiplied by the length of the projection. As a result, the relevant angle of rotation will be smaller, the more closely the angle α between gesture vector and reference axis approaches 90 degrees (see Fig. 46).

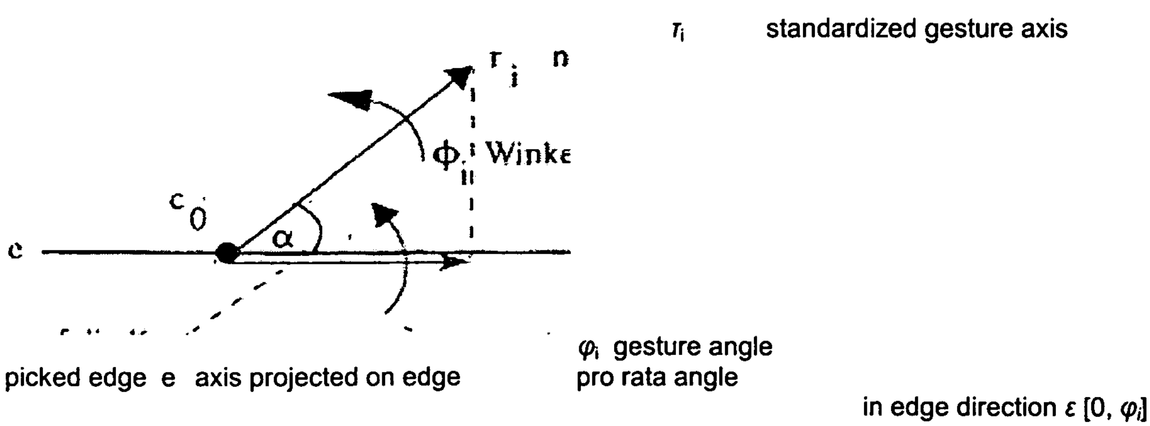


Fig. 46: Imaging of gesture rotation on axis of rotation

The total angle of rotation Φ is thus given by:

$$\Phi = \sum_{i=0}^{z} \phi_i \cdot \frac{e \cdot r_i}{\|e\| \cdot \|r_i\|}$$

The procedure described ensures *kinesthetic correspondence* [115] in 3D. That is, the user must rotate the 3D input device about the axis around which the picked object is to be rotated, just as he would rotate a real object in his hand about the axis around which he would like to rotate it. Thus, a stimulus-response correspondence is produced for rotation as well.

Calculation of the translation executed by the 3D cursor over the gesture recognition period is comparatively trivial. It may be pointed out again that during this period, the 3D cursor changes its position virtually only, not visually.

The gesture vector turns out to be equivalent to the rubber-band vector:

$$g = c_z - c_0$$

Classification of Gesture

The decision as to whether the user has executed a rotation gesture or a translation gesture is made finally by comparison with the thresholds, rotation having priority over translation. This has proved sensible, because a rotation of a 3D input device is always attended by a translation. The motor abilities of man do not permit performance of a rotation alone; some -- even if not much -- translatory motion is always present. The mechanical and sensory properties of 3D input devices contribute their share to the circumstance that rotations cannot be executed wholly without translatory components.

Therefore:
If $\Phi > \rho$, then execute rotation.
If

$$\operatorname{acos}\left(\frac{g \cdot e}{\|g\| \cdot \|e\|}\right) < \tau$$

, then execute translation or change of parameters.
Otherwise, reject gesture.

This completes the gesture classification phase. The events picked up to find the gesture are not applied to the object, i.e. the object remains intact up to the present time. To indicate the recognized gesture to the user, a visual echo is inserted into the scene (see Fig. 48). Now the modification phase begins, in which direct manipulation of the picked object takes place according to the rules of gesture interpretation described in the next subchapter.

4.2.6.2 Modification Phase

When the gesture recognition phase is completed, the TCBM passes seamlessly into the modification phase, while the user is continuing his gesture. At the transition from gesture recognition to modification phase, a visual feedback may be inserted into the scene, and the freedom of motion of the cursor limited for all further events. During the modification phase, not only is the object altered in directly manipulative manner, but, with each event, the position or perhaps the image manifesting the visual feedback is adapted.

Upon viewing of various types of volume primitives, it soon becomes clear that one and the same gesture applied to different primitives is not necessarily able to lead to a similar modification. Thus, the following modifications are to be supported by only two kinds of gestures (translation and rotation):

- Change of a parameter
- Simultaneous change of several parameters (scaling)
- Rotation of the object
- Translation of the object

For this reason, a context-dependent interpretation of the gesture is required, coinciding as best may be with the user's intention. Like the interaction techniques for producing primitives, the rules of modification must also work correctly in semantic terms. Here, the volume primitives should behave as though they consisted of rubber, a modification being capable of functioning locally. For example, a displacement of the lid surface of a cylinder should not necessarily be attended by a modification of the base surface.

The interpretation of modification gestures in a manner conforming to expectation was determined experimentally in terms of a prototypical transformation for the rectangular solid and cylinder as primitives. The first column contained the picked topological element. In column 2, the gesture is represented in terms of the particular object type in the model coordinate system (MKS) of the object. The third column gives the rule of transformation, and the fourth column, any exceptions to that rule. Note that in Table 4, all translatory gestures leading to change in one or more parameters of an object are expressed in terms of scaling. This form of representation was chosen to simplify the mathematical description. Actually, such translatory gestures are imaged on parameter changes of the volume primitive.

Definitions and Abbreviations

s scaling vector before modification

m modification vector, found from gesture vector after application of the restriction of motion for the cursor and projection into MKS; in Table 4, m is represented as an arrow

n normal vector

opp *opposite picked point*: the point given by double the vector of the pick position to the center of the primitive

cobf *center of bottom face*
center of bottom surface

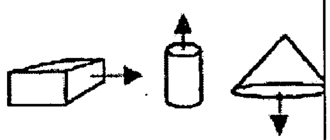
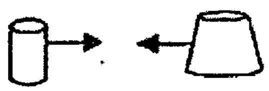
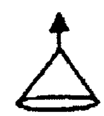
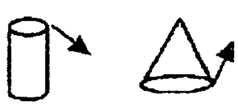
copf *center of opposite picked face*
center of surface opposed to the planar surface adjacent to the picked edge

origin zero point for scaling

$|v|$ vector, standardized with respect to v

$||v||$ length/absolute value of a vector v

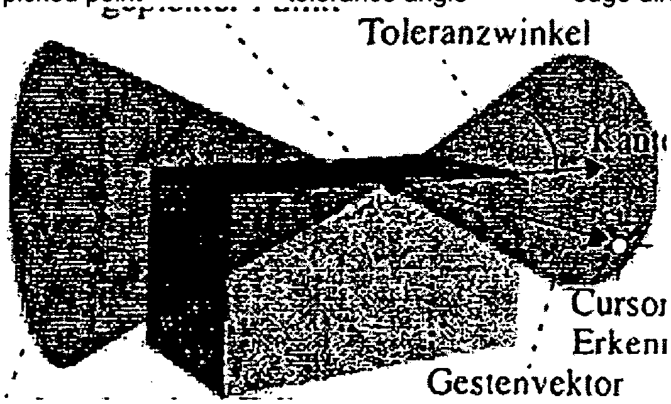
Table 4. TCBM modification rules

Topological Element	Gesture	Transformation Rule	Exception
surface	orthogonal to normal	Translate object in plane	
planar surface	direction of normal 	$s' = s + m$ origin = *opp*	
Non-planar surface	direction of normal, $n_z = 0$ 	$s' = s + m$ origin = *cobf*	sphere: cursor limited to n $s'_i = s_i + ((\lvert m\rvert * n) * \lVert m\rVert)$, $i \in x,y,z$ origin = center of sphere 
vertex	Rotation	rotate object about vertex	
	Translation 	$s' = s + m$ origin = *opp*	cone: cursor confined to z-axis 
edge	direction of edge/tangent	Translate object along line	
	rotation about edge	rotate object about edge/tangent	
circular edge	direction of vector of curvature 	$s'_i = s_i + ((\lvert m\rvert * n) * \lVert m\rVert)$, $i \in x, y$ origin = *cobf*	
	orthogonal to vector of curvature 	$s'_z = s_z + m_z$ $s'_{xy} = s_{xy} + ((\lvert m_{xy}\rvert * n_{xy}) * \lVert m_{xy}\rVert)$ origin = *copf*	
elliptical edge	direction of vector of curvature	$s' = s + m$ origin = *cobf*	
	orthogonal to vector of curvature	$s' = s + m$ origin = *copf*	

Prismatic object shapes may be treated like the corresponding conical shapes. Then horizontal edges in the model coordinate system must be distinguished from vertical ones to achieve an interpretation conforming to expectations; likewise peripheral, bottom and top surfaces.

An example will clarify the mode of operation of the TCBM. Fig. 47 shows how a rectangular prism can be modified by various gestures after picking the same position in different ways. In Fig. 47a, the 3D cursor, after selection of the edge, is moved in the direction of that edge. At expiration of the gesture recognition period, the cursor lies in the compartment given by the edge direction and the translation threshold angle (visualized in Fig. 47 by a semi-transparent envelope[2]). Now a visual echo is inserted (see Fig. 48a), which indicates the recognized modifying intention to the user. All subsequent instructions are imaged on and restricted to the straight line defined by the edges. The rectangular prism can be moved only along the straight line. In Fig. 47b, following the gesture recognition period, the cursor is located in the compartment defined by the surface orthogonal to the edge and the translation threshold angle (likewise visualized as semi-transparent compartment). Now the visual feedback represented in Fig. 48b is inserted. All subsequent interactions are imaged on the surface orthogonal to the edge passing through the picked point. The prism can now be scaled in two directions.

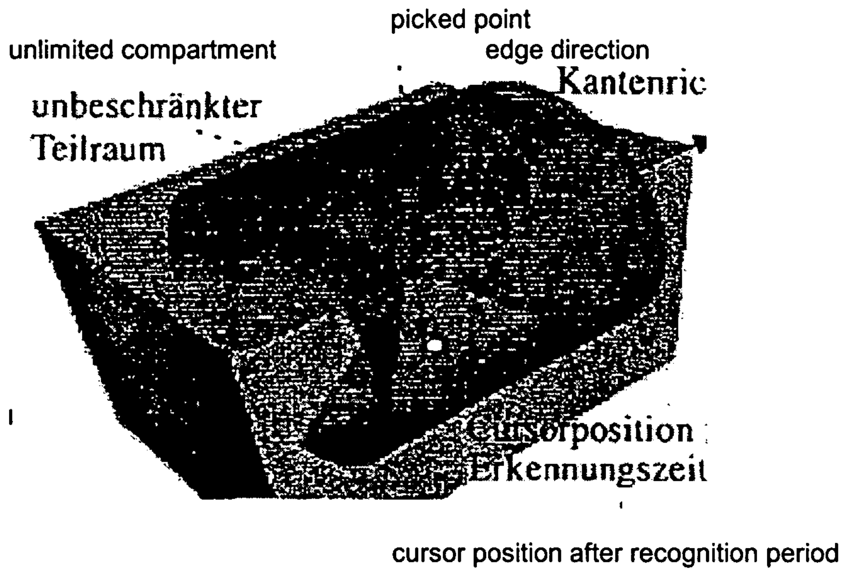
picked point tolerance angle edge direction



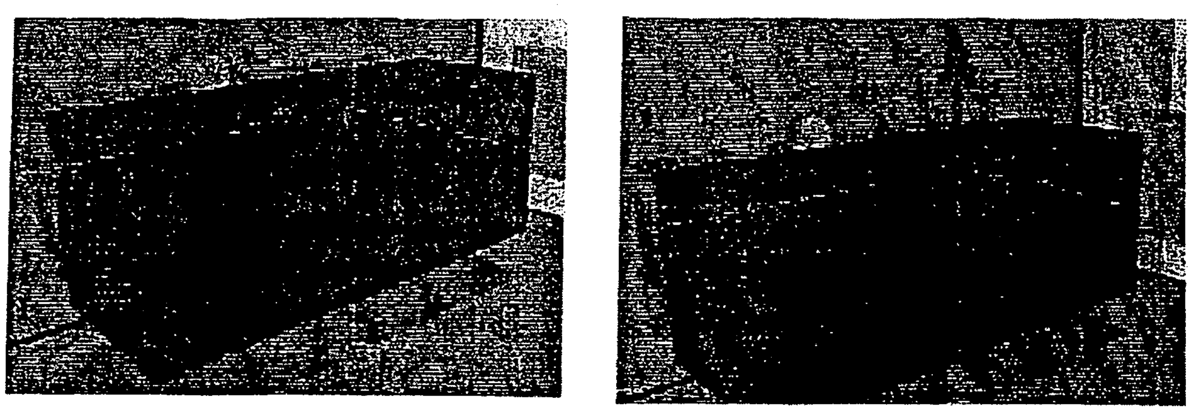
cursor position
unlimited compartment for gesture classification gesture vector recognition period

a) displacement along a line

[2] This space is open in the direction of the floor surface, of the cone used for visualization



b) scaling of a prism
Fig. 47: Example for topology-based limited modification technique



a) translation along edge
b) scaling of two parameters
Fig. 48: Visual feedback during TCBM

The visual feedback, in the case of translation along a line, consists of a double arrow (see Fig. 48a), so that the user will realize that he can displace the prism in two directions. In the case of scaling in two dimensions, the graphic echo consists of a transparent surface orthogonal to the edges at the picked position. Two bi-directional arrows indicate the degrees of freedom (see Fig. 48b).

It may be pointed out once again that during the modification phase, the changes are carried out, i.e. calculated and visualized, only by the graphic manager. After conclusion of the modification phase, the change is transferred to the mathematically correct object representation in the modeler (cf. chapter 3.3). In this way, a direct manipulation in real time is possible. As in the case of object production, the interaction may also be discretisized at the time of modification, so that precise manipulations can be performed (see chapter 4.2.9).

Respectfully submitted,

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